

**PROPERTIES OF MINOR IONS IN THE SOLAR WIND AND
IMPLICATIONS FOR THE BACKGROUND SOLAR WIND PLASMA**

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Annual Report

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Annual Report on the grant NAG5-10996 “Properties of minor ions in the solar wind and implications for the background solar wind plasma”

1.1 Scope of the Investigation

Ion charge states measured in situ in interplanetary space carry information on the properties of the solar wind plasma in the inner corona. The goal of the proposal is to determine coronal plasma conditions that produce the in situ observed charge states. This study is carried out using solar wind models, coronal observations, ion fraction calculations and in situ observations.

1.2 Progress Made During Period 06/01 01 to 05/31 02

It had been a puzzle for quite some time that spectroscopic measurements in the inner corona, above coronal hole regions, indicate electron temperatures far too low to produce the ion fractions observed in situ in the fast solar wind. It was shown by Esser and Edgar (2000 and 2001) that the coronal and in situ observations in the fast solar wind can be reconciled if the electron distribution function in the corona deviates from a Maxwellian distribution relatively close to the sun where the ion charge states are formed, and/or if differential flow speeds between ions of the same element exist (Esser and Edgar 2002). In the case of Si ions these flow speeds have to be rather large. In these studies the ion flow speeds were not calculated from a consistent model, but were assumed and scaled to the proton flow speed. In a more recent study (Chen, Esser and Hu 2002) we investigated whether these flow speeds can actually exist. In the first case we focused on O ions using a 3-fluid background solar wind model to describe the electron, proton and helium expansion and a 2 fluid model to describe the minor ion flows, O^{+5} and O^{+6} and O^{+7} and O^{+6} . It was shown that flow speed differences between these ions of order 2 to 3 can exist. In the case of O^{+5} these differences were important in the formation of the ion fraction. In the case of O^{+7} , however, the flow speed differences started to develop beyond the region where the ion fractions are formed ($1.2 R_S$), that means they developed in the region where the O^{+7} and O^{+6} ions had already decoupled. In the case of O the differential flow speed or non-Maxwellian tails are not very crucial since an increase of the electron temperature of say 10% above the values observed by SUMER gives the ion fraction values that are observed in situ in the fast wind by e.g. SWICS. On the other hand, this is not the case for Si which decouples at a larger distance (about 2.5 to 3 R_S).

We are currently working on an extension of the 2 fluid minor ion code to a 5 fluid Si code. In the case of Si there are many more charge states present simultaneously which makes an extension to a larger number of equations necessary. This study should be interesting because the region where Si forms extends to much larger distances from the sun, and because the Si ion fraction observed in situ requires much higher temperatures, non-Maxwellian tails and/or differential flow speeds.

We have also started a similar investigation for the slow solar wind. Preliminary results show that the discrepancy between observed coronal electron temperatures and in situ ion charge states also exist in the slow solar wind.

1.2 Future Plans

The next few months we will use to finish a paper describing the results of the study of the slow solar wind and we will continue to work on the solar wind minor ion codes to investigate how large the differential flow speeds can be in the corona assuming different background solar wind parameters and different heating functions for the ions. These studies can provide additional information on minor ion flow speeds which can not be observed directly in the corona but which are important for coronal heating models, e.g. ion cyclotron heating models.

2. Publications in Journals and Invited talks at Meetings Fully or Partially Funded by the Grant

1. R. Esser and R. Edgar, Differential flow speeds of same element ions: Effects on solar wind ionization fractions, *Astrophys. J.* 2002.
2. Y. Chen, R. Esser and Y.-Q. Hu, A theoretical model for O^{+5} (O^{+7}) ions in the fast solar wind, submitted to *J. Geophys. Res.* Feb. 2002.
3. R. Esser, O. Lie-Svendsen and R. Edgar, Discrepancy between coronal plasma parameters and in situ ion fractions in the slow solar wind, to be submitted to *Astrophys. J.* April 2002.
4. S. Cranmer and R. Esser, Cyclotron Resonance of Ions in the Solar Corona: Observations and Models, invited talk at IAGA Meeting Vietnam, 2001.
5. R. Esser, Review Talk on Solar Wind Observations and Modeling, invited talk at Plasmasymposium, Norway, February 2002.
6. R. Esser, Review Talk on the Observational and Theoretical Constraints on the Acceleration Region of the Solar Wind, Solar Wind 10 Meeting, Pisa, Italy, June 2002.

Ion Fractions in the Solar Wind

$$\frac{1}{A} \frac{\partial}{\partial r} (n_i v_i A) = n_e (n_{i-1} C_{i-1} - n_i (C_i + R_i) + n_{i+1} R_{i+1})$$

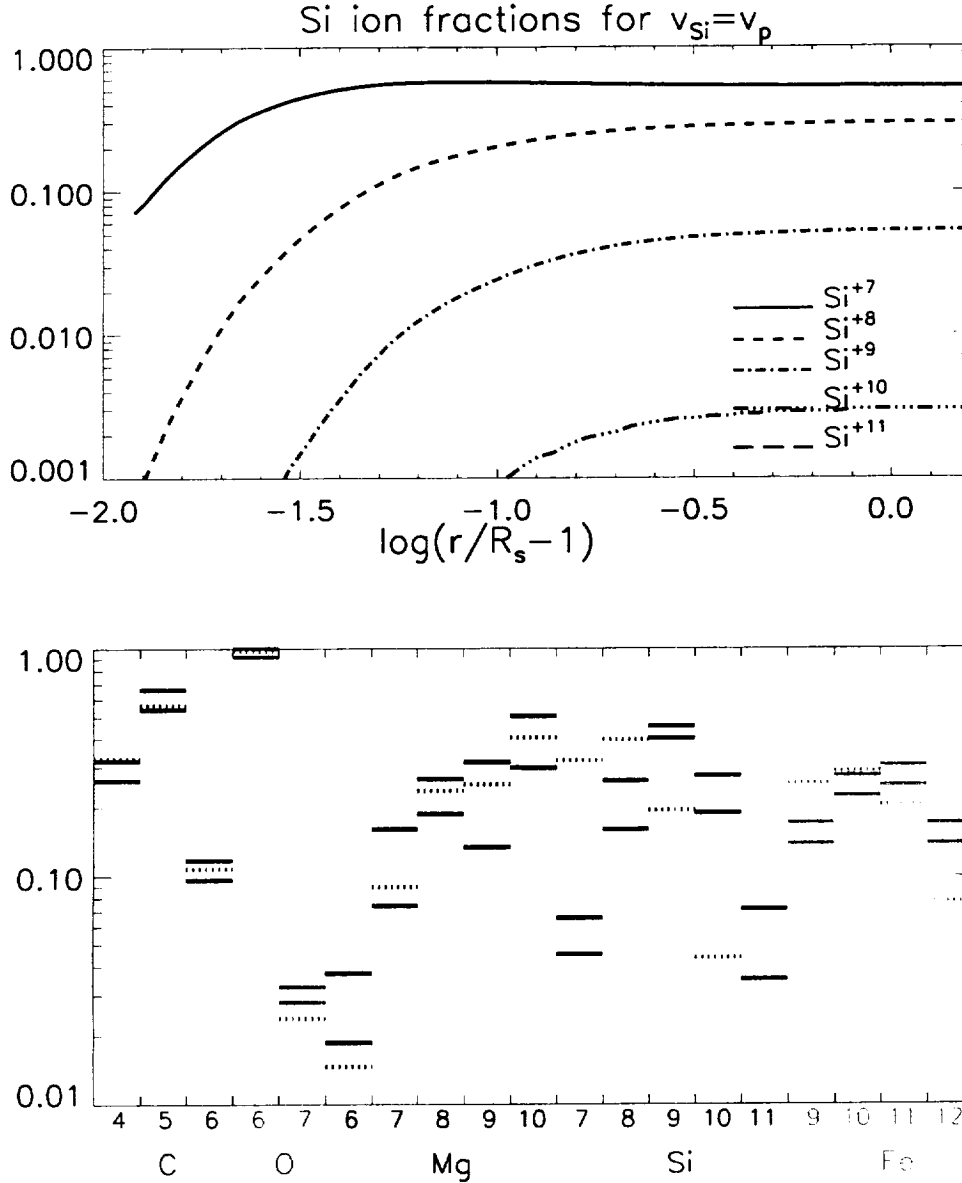


Fig. 1. A set of 15 continuity equations is solved simultaneously for Si for a realistic background solar wind. At a certain distance from the coronal base the ions decouple from each other and remain constant above that distance (upper panel). This is due to the decrease of the electron density with radial distance, and an increase of the ion flow speeds. The charge states measured in situ in the solar wind carry therefore the history of their formation process with them into interplanetary space. The electron temperatures measured in the inner corona are not high enough to produce the in situ ion fractions (upper and lower values for the high speed solar wind are shown in the lower panel as solid lines) if it is assumed that ions of the same element flow with the same speed, and the electron distribution function is Maxwellian. In particular Si and Fe are underionized compared to observed values, even if all coronal parameters are assumed to be as favorable to the ionization process as possible without violating the observations in the corona. This is shown in the lower panel (dotted lines).

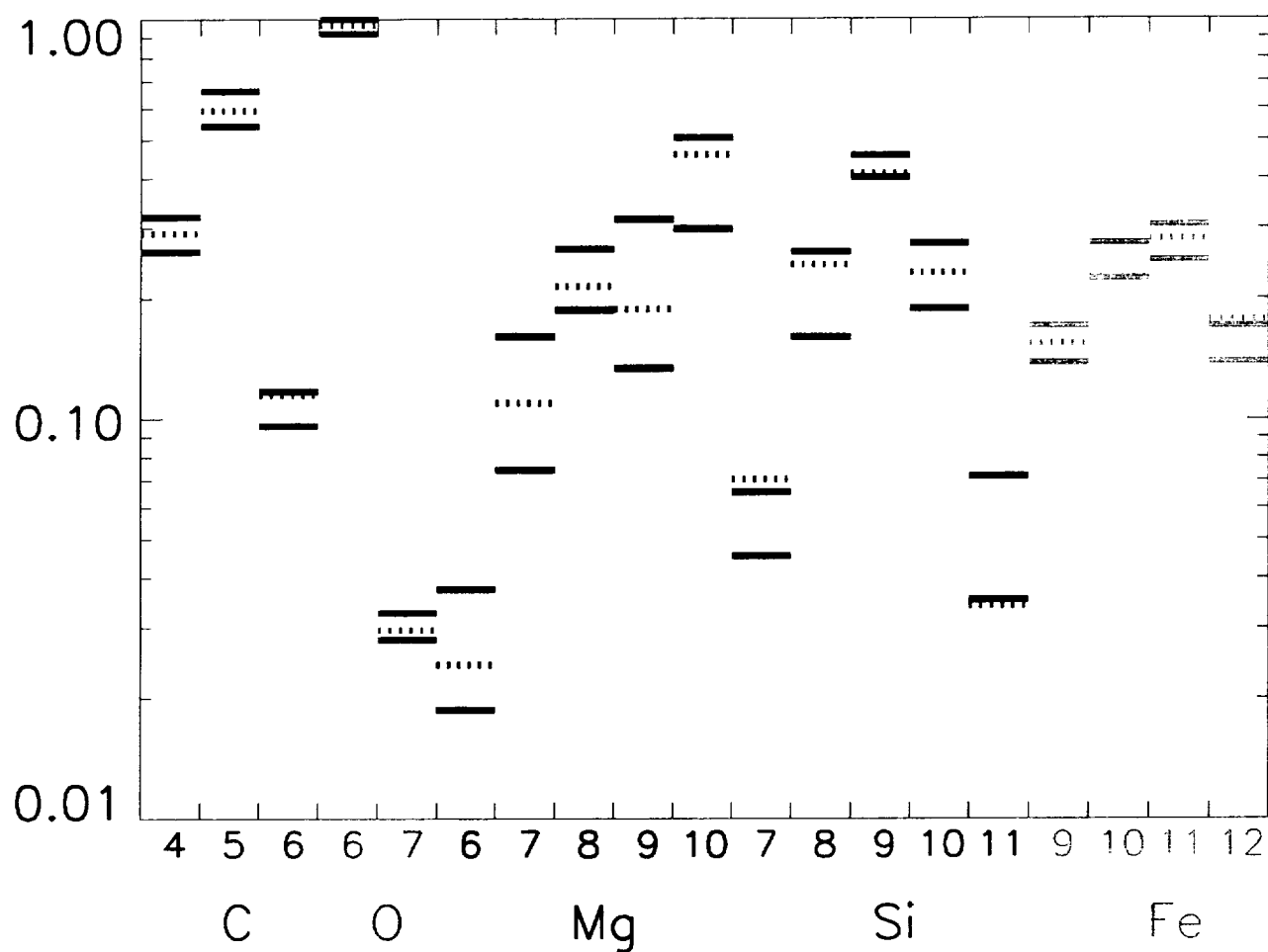


Fig. 2. Limits on the ion fractions observed by SWICS/Ulysses (solid lines) from Ko et al. (1997), and calculated fractions (dashed lines). The background solar wind parameters are the same as in Fig. 1, but it is assumed that ions of the same element flow with significant speed differences.